Status of the Cryogenic Anticoincidence detector for ATHENA X-IFU: DM and SM models

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- XIFU - X-ray Integral Field Unit
- Anticoincidence CryoAC
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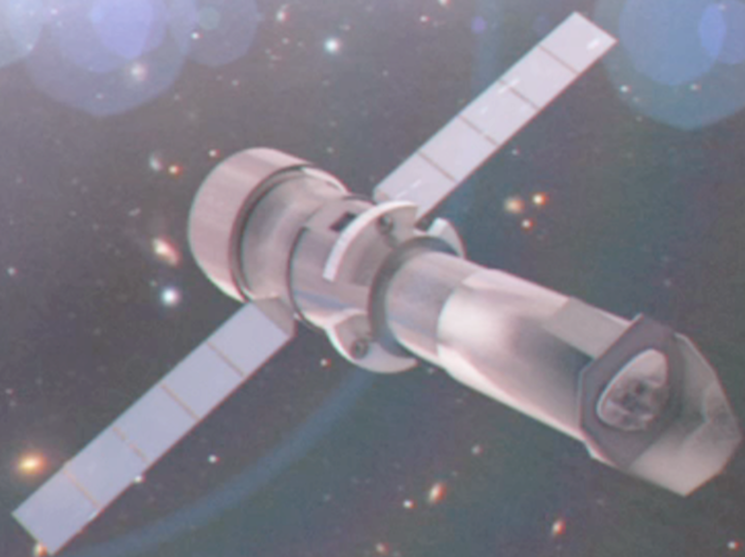
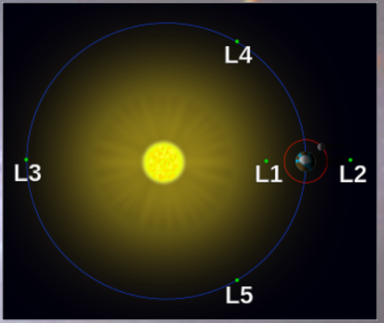
  - ❑Phonon simulation
- Demonstration model (DM)
  - ❑ Structure and production
  - ❑ First tests
  - ❑ Problem resolutions
- Structural model (SM)
  - ❑Structure and production
  - ❑Vibration tests



Athena observatory

ATHENA will be an observatory for X-ray (0,2-12 keV).
It will be on satellite on L1 Lagrange point



Athena physics:

- Formation and development of Hot gas Cosmological structures;
- Formation and evolution of massive black holes;
- Gamma-ray burst and energetic events;
- Others astrophysics fields(interaction of magnetic field with star wind, young and neutron star X-emissions, etc…)

Athena schedule

- ✓ ``Hot energetic universe theme`` selected by ESA (Nov. 2013)
- ✓ Athena mission selected (2014)
- ✓ Phase A completed (Nov. 2019)
- ✓ Expected implementation (end of 2022)
- ✓ Launch expected in 2030-31
- ✓ Operations 4+6 years

Collaboration

The project involves several universities and research institutes of eleven countries of EU, USA and Japan. In Italy ASI, INAF, INFN and several universities are involved .

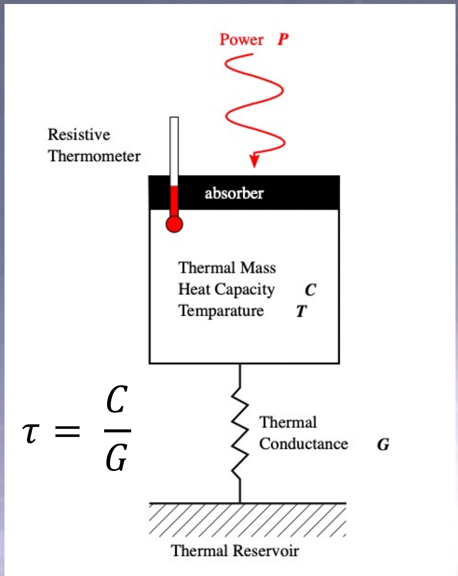
Apparatus

The satellite will consist of three parts:

1. **A X-ray telescope with a focal length of 12 m and effective area of 1.4 m^2 at 1 keV;**
2. **An X-ray detector with high resolution based on criogenic microcalorimeter (TES,Transition Edge Sensor). They will operate at ~50 mK with a resolution of 2.5 eV and 5 arcmin of visual field;**
3. **A silicon detector with a lower resolution (~ 100 eV) but large visual field (~40 arcmin, WFI Wide Field Imager).**

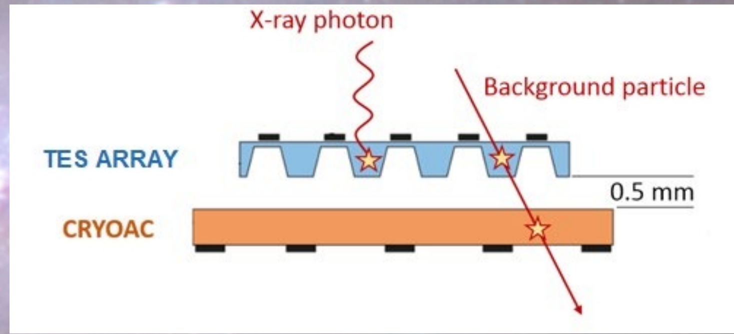
- ❑ Each interesting cosmic object will be observed about 300 times each year for a total of 10^5 seconds.
- ❑ Redirection will be possible to observe events like gamma ray burst with an expected rate of 2/month.

X-IFU detector

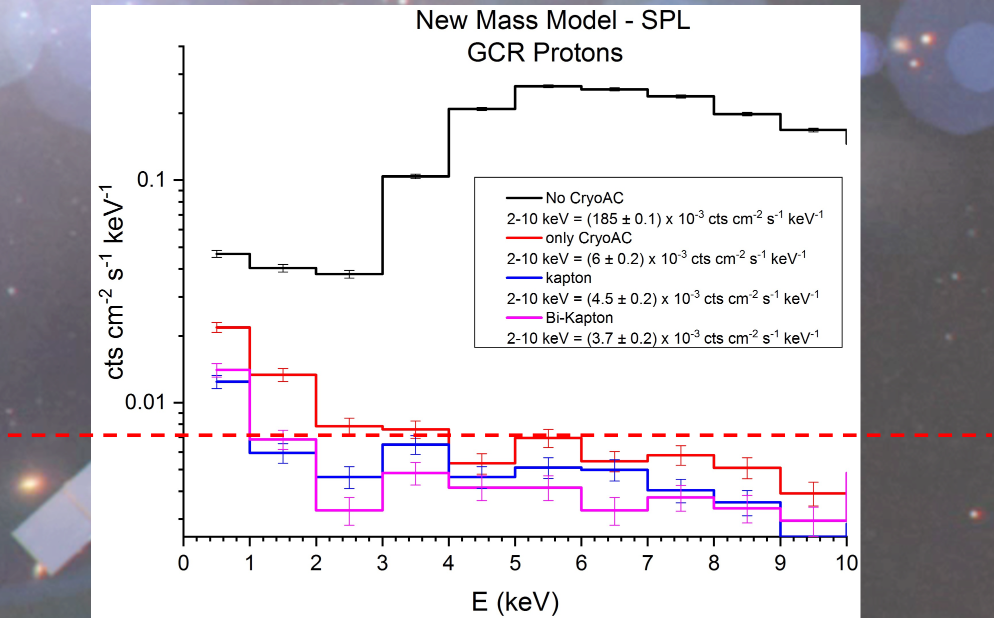


The detector will be done by two parts.

1. Ti/Au TES array with absorber (250x250 μm^2)of Cu/Bi, 40 pixel for each channel , 96 channels , 3840 pixel read by SQUID
2. An anticoincidence (CryoAC) done by a silicon absorber read by Ir/Au TES Array

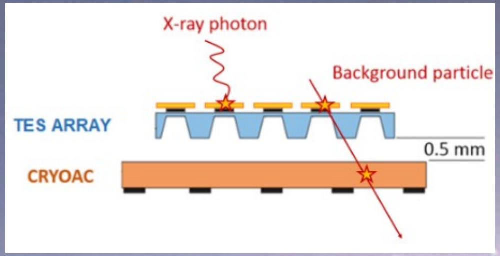


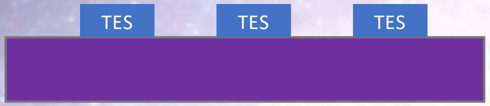
Charged particle from cosmic rays could simulate signal in the main detector: an anticoincidence is needed.

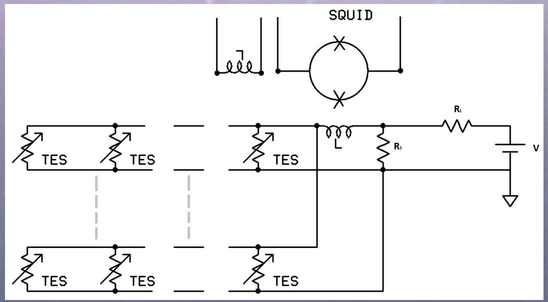


The Non-X-ray Background requirement is 5 10^{-3}cts/cm^2/s/keV (2-10 keV TBC).

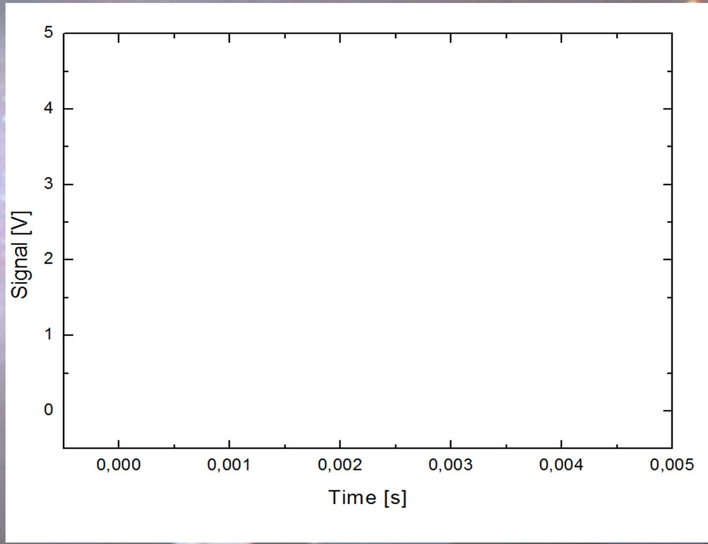
Working principles





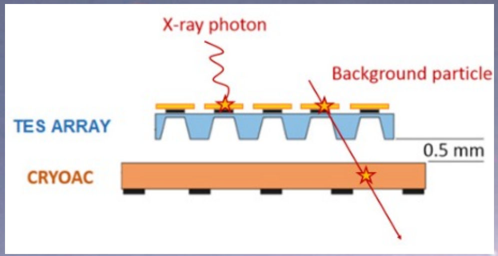


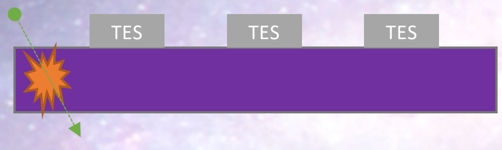
❖ Particle hits the silicon absorber



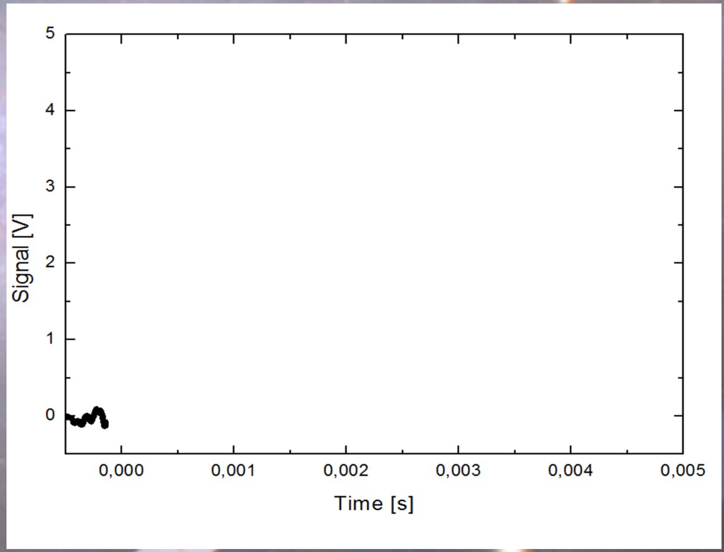
<u>TES network read in parallel as a single object</u>

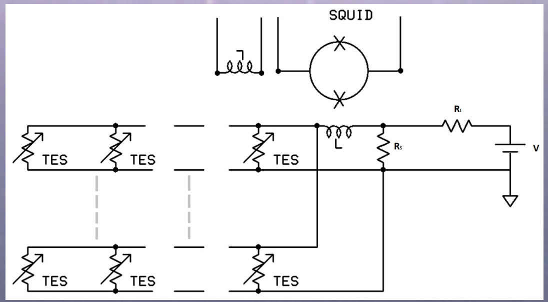
Working principles





- Particle hits the silicon absorber
- Particles release energy inside the silicon substrate





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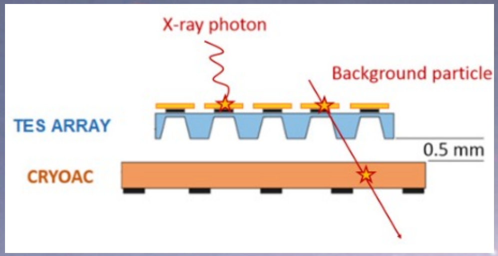
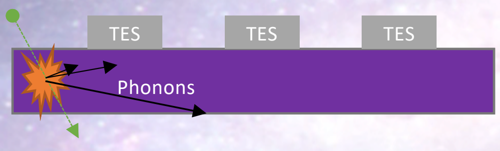
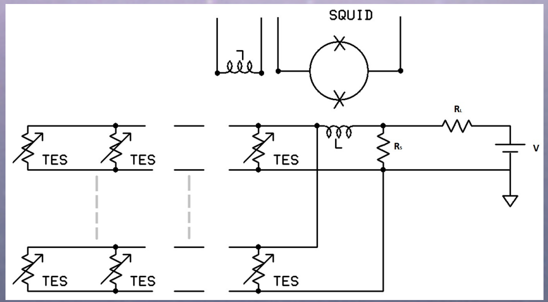
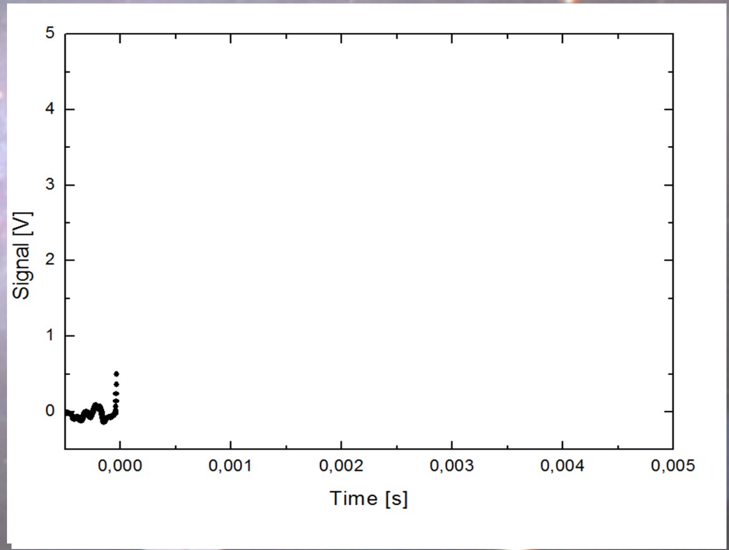




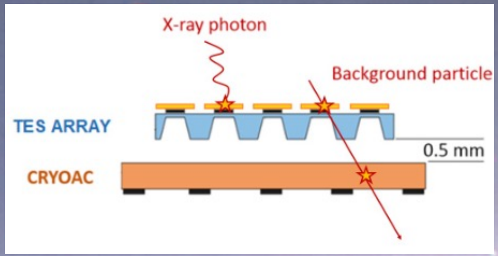


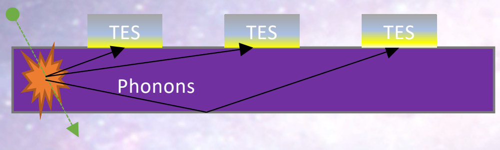
- Particle hits the silicon absorber
- Particles release energy inside the silicon substrate
- The energy produces phonons



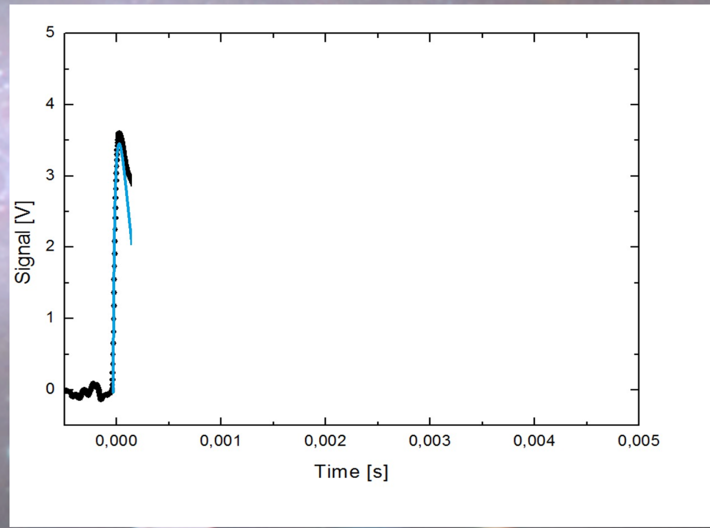
TES network read in parallel as a single object

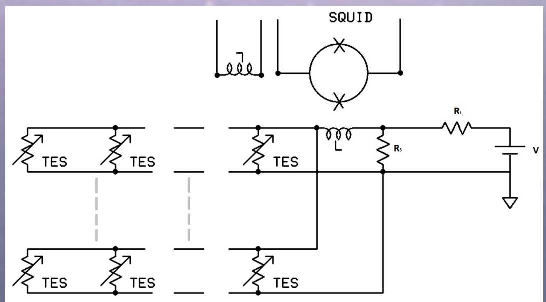
Working principles





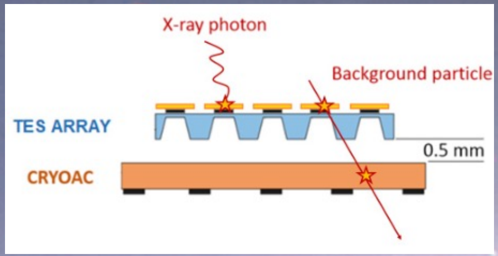
- Particle hits the silicon absorber
- Particles release energy inside the silicon substrate
- The energy produces phonons
- Phonons hit the TES network and increase its temperature



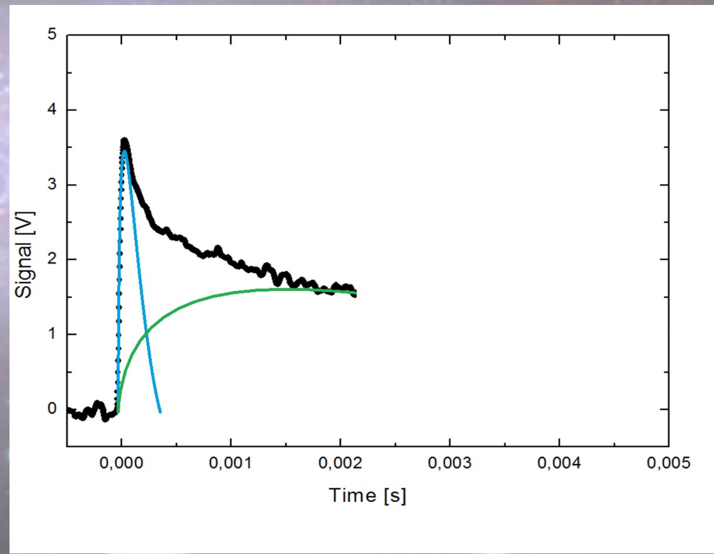


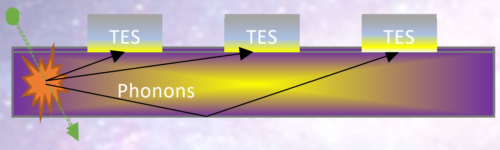
<u>TES network read in parallel as a single object</u>

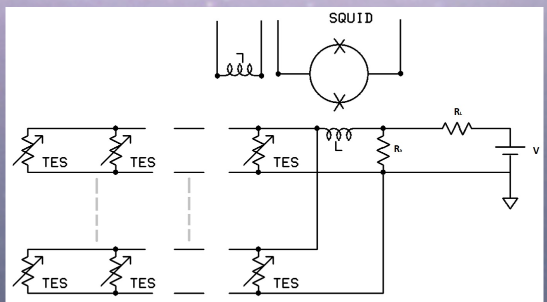
Working principles



- Particle hits the silicon absorber
- Particles release energy inside the silicon substrate
- The energy produces phonons
- Phonons hit the TES network and increase its temperature
- Absorber Thermalization

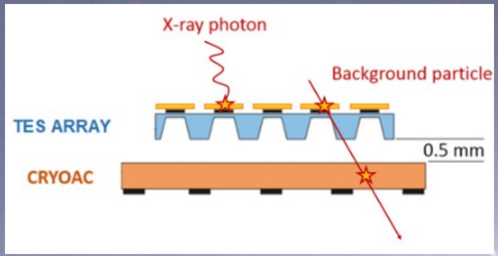


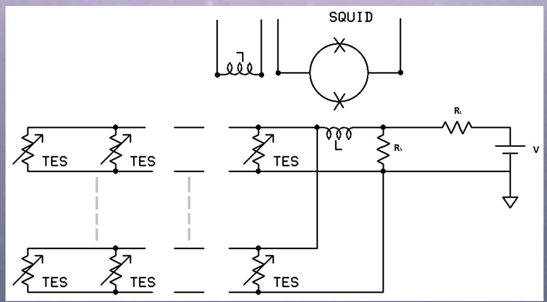




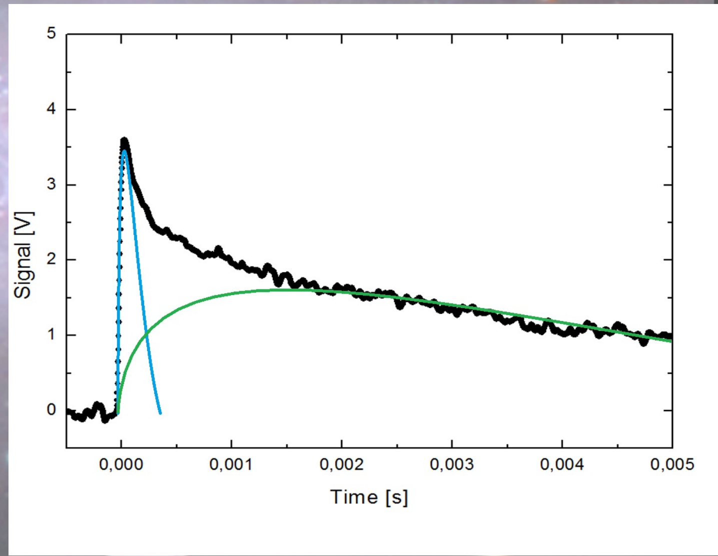
<u>TES network read in parallel as a single object</u>

Working principles





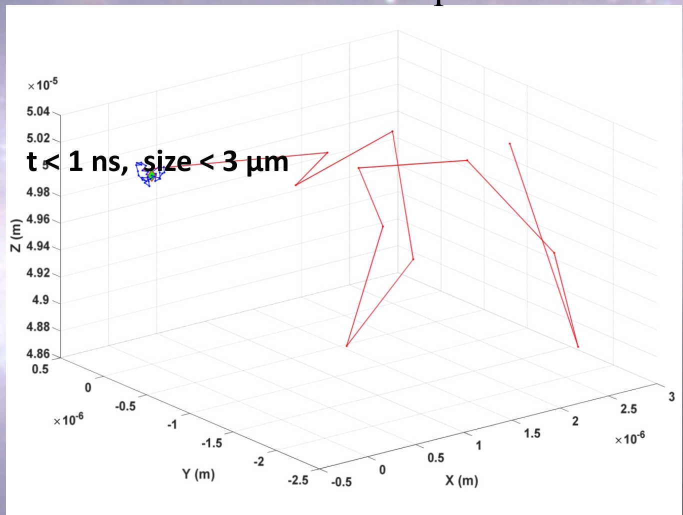
- Particle hits the silicon absorber
- Particles release energy inside the silicon substrate
- The energy produces phonons
- Phonons hit the TES network and increase its temperature
- Absorber Thermalization
- Thermal relaxation

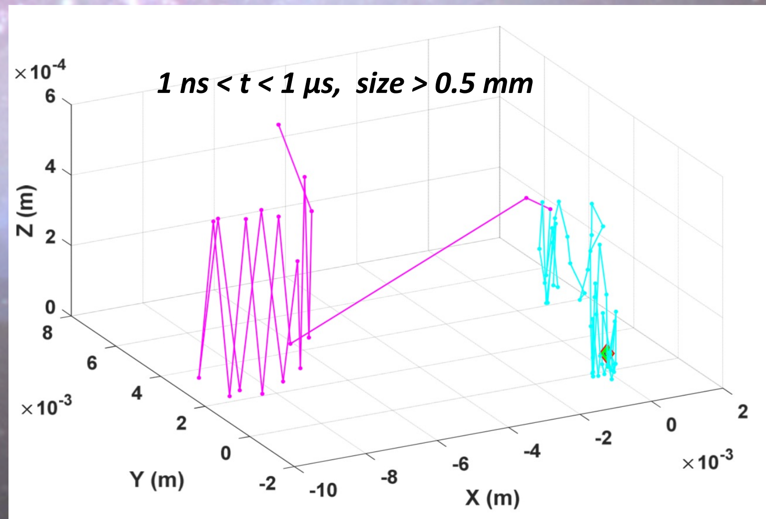


<u>TES network read in parallel as a single object</u>

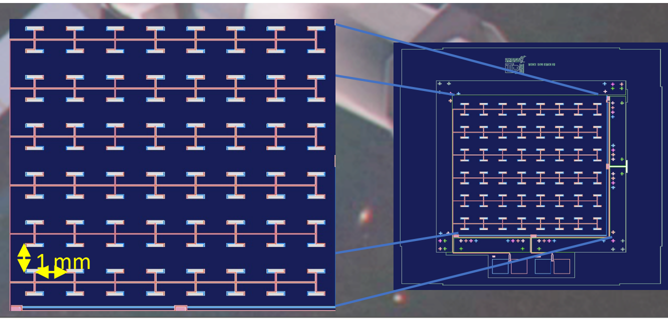
Phonon dynamics

Simulated trajectory of a phonon: at the very beginning this is dominated by the elastic scattering from Si isotope and have mean free path in sub-um and um scale. At each anharmonic decay, 2 lower energy phonons are generated: here only one phonon is represented. The track changes colour when the energy decreases: from green, to blue and red (left). Cyan and magenta (right) tracks correspond to the second phase, almost ballistic, in which the pathlength is comparable with the size of the chip. The reflections at the surface are simulated with parameters taken from literature.

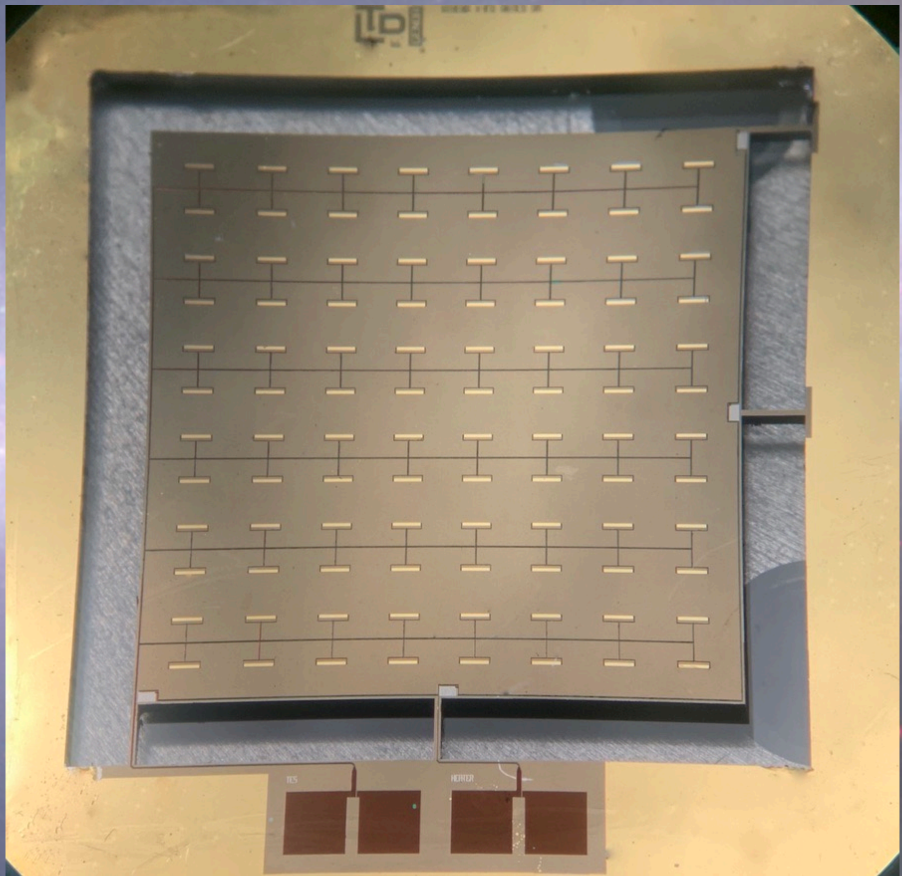




TES are placed on the absorber with a step size comparable with the athermal phonons interacting area.
Athermal test is ongoing : acquisition of pulses read by a detector with a column of TES or a single TES while moving the 241-Am x-Ray source. The Athermal peak will change with the emitter source position.

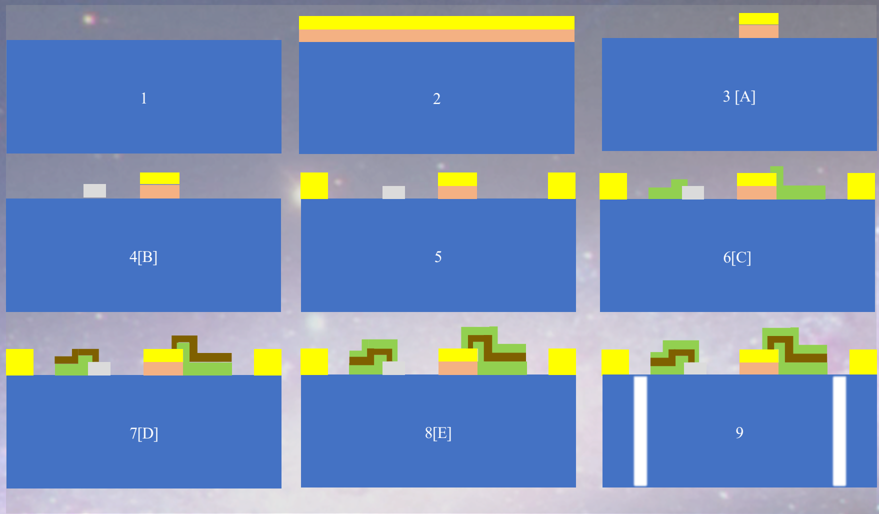


Demonstration Model (DM)

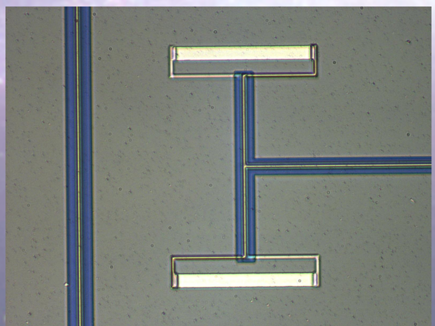


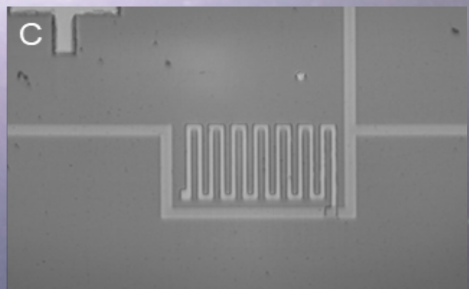
- **1 cm^2 active area**
- **96 TES with 100mK Tc Ir/Au bilayer**
- **525 µm thick Silicon substrate and absorber**
- **4 silicon beams for a freestanding absorber**
- **4 heaters to move the absorber temperature and test the detector**
- **Anti-inductive overlapped wiring with alternate TES biasing (is required a <u>magnetic field much smaller than 1 µT at 1 mm distance</u>)**

Fabrication processes



1. Silicon chip
2. Ir:Au bilayer deposition by PLD and e-beam
3. TES by Ir/Au bilayer etching
4. Pt heaters fabrication
5. Au thermalization layer deposition on rim
6. Niobium wiring (lower strip) fabrication
7. Silicon oxide insulation
8. Niobium wiring (upper strip) fabrication
9. Deep RIE:
    I. Al Hard-mask deposition
    II. Etching using bosch process
    III. Removal aluminum mask

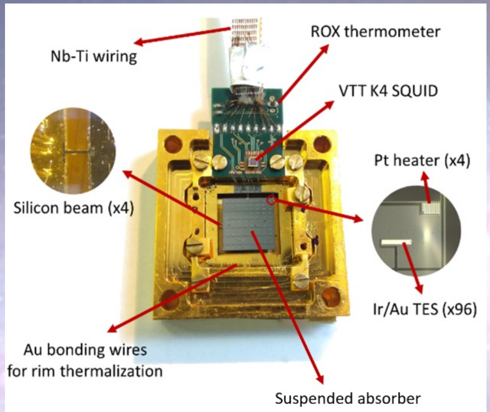


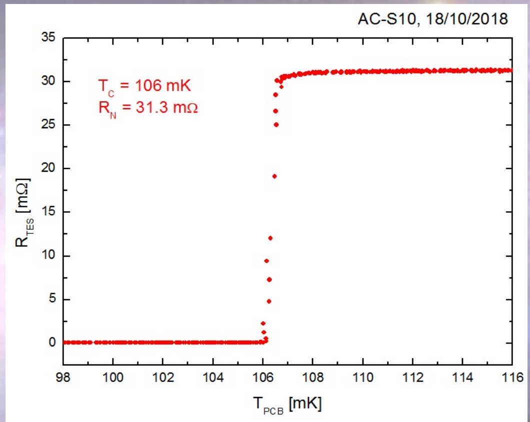


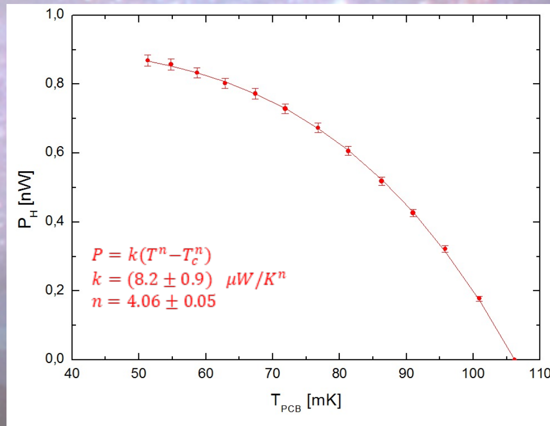
At present we are qualifying this list of processes to increase the detector production yield

DM test at SRON

Two working models has been produced and one of them has been integrated and tested at SRON facility





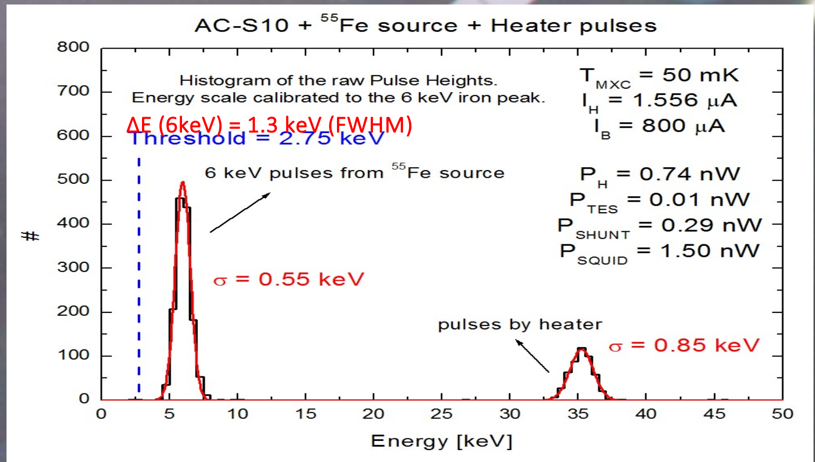


TESs:

- Ir:Au bilayers 240:80 nm thickness
- Tc = 106 mK
- <u>R_0 = 31.3 mΩ</u>

Power dissipation:

- 3 nW @ 50 mK (less than 1 nW on the Heaters)

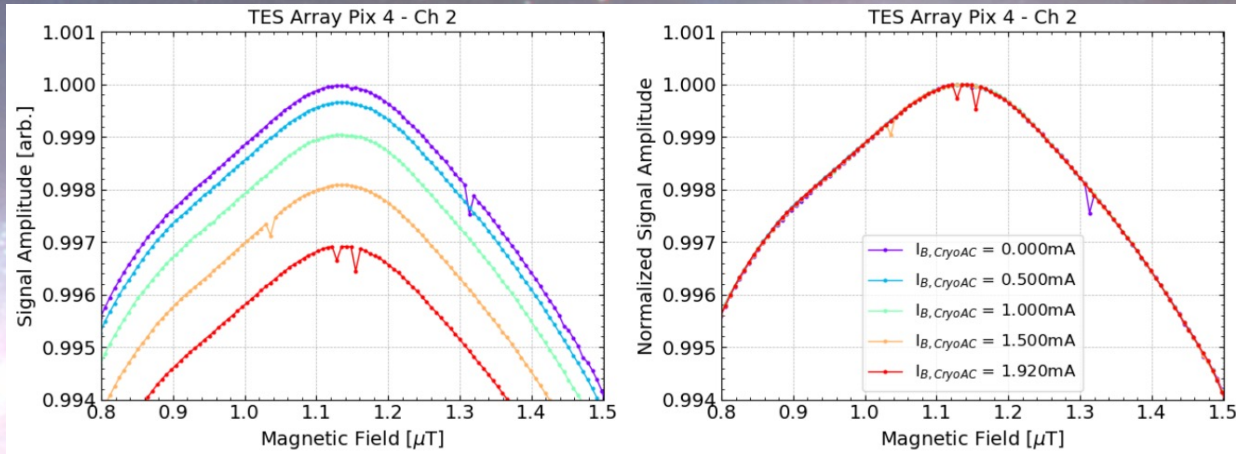


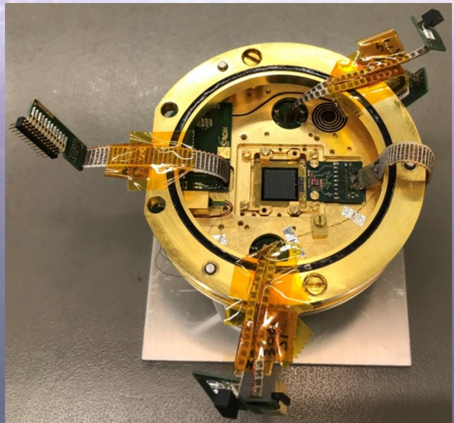
DM test at SRON (2)

- **Magnetic field scans:**

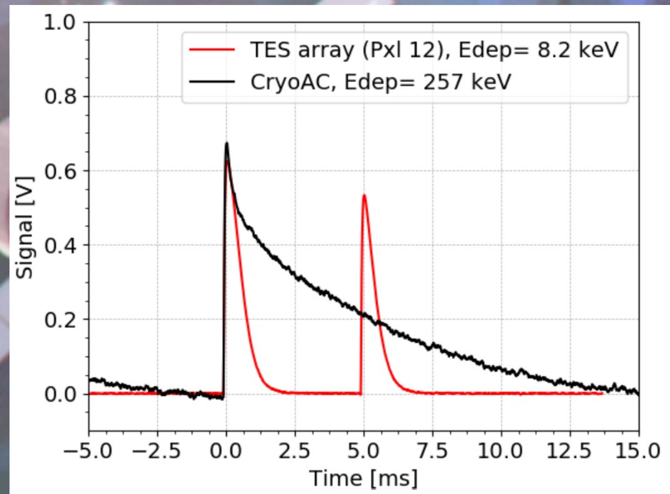
The CryoAC bias current does not affect the magnetic environment on TES array pixels.

Only an offset due to some thermal effect is noticed. *(credits NASA/SRON)*





- Muon-coincidence and an x-ray detected in combination with the Demonstration Model TES-Array *(credits SRON)*.

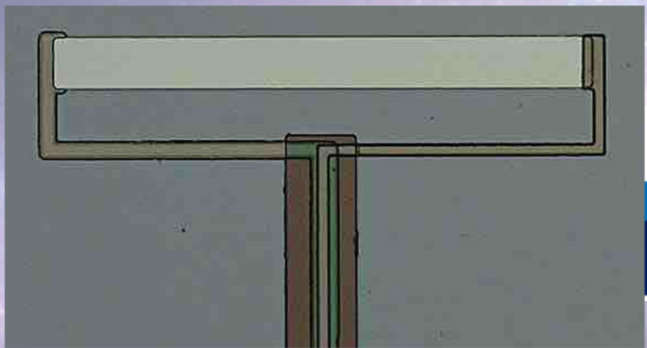


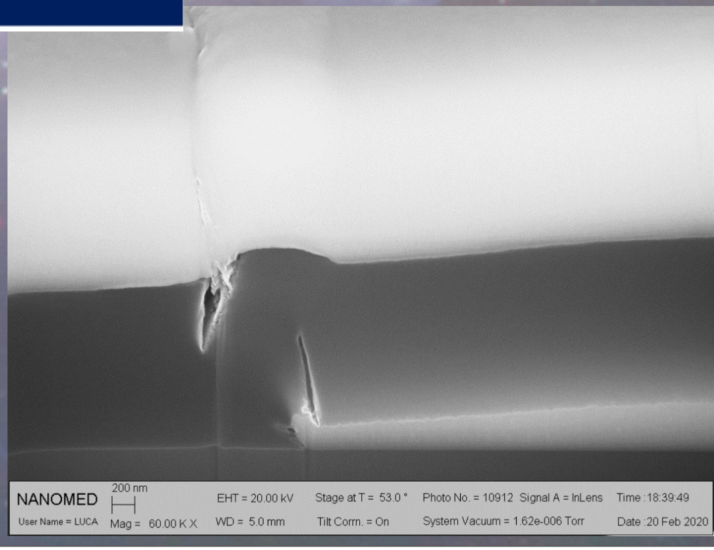
DM problems

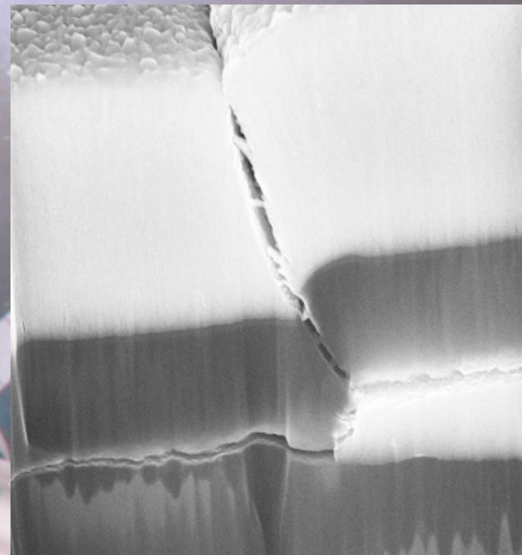
Two problems emerged from tests:

1. Parasitic resistance related to bias current
2. Contamination of DM

FIB-SEM analysis show a deep fracture of Nb-SiOx bilayer in the wiring step coverage





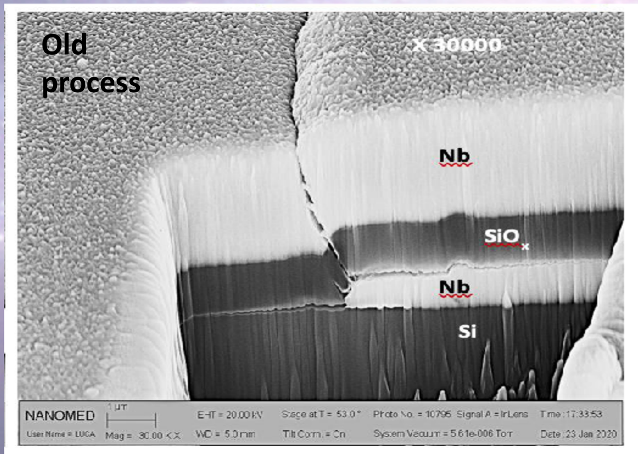


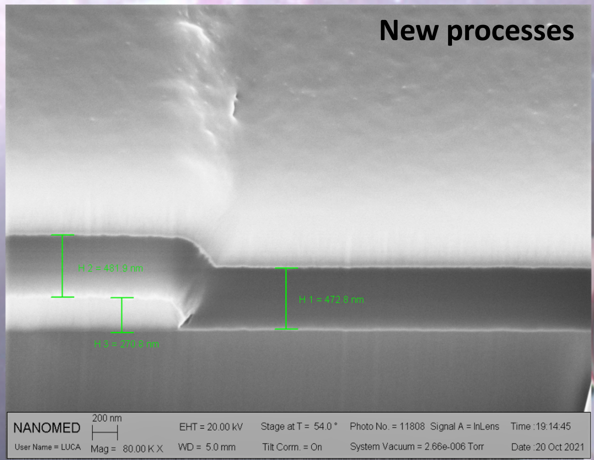
This fracture creates a bad contact and could induce parasitic resistance as function of current (transition to normal resistance of some parts due to current density)

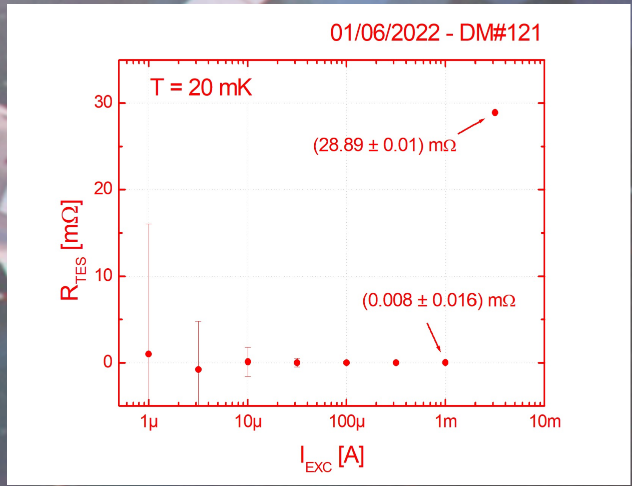
DM parasitic resistance

- Reduce the slope of the deposition working on microlithography
- Change the thickness of deposited films

Several DM has been produced to test the new processes



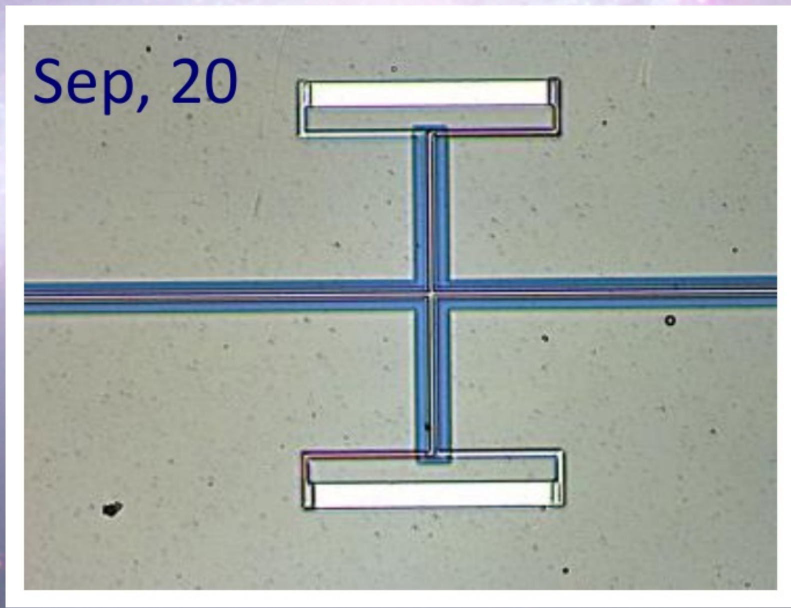


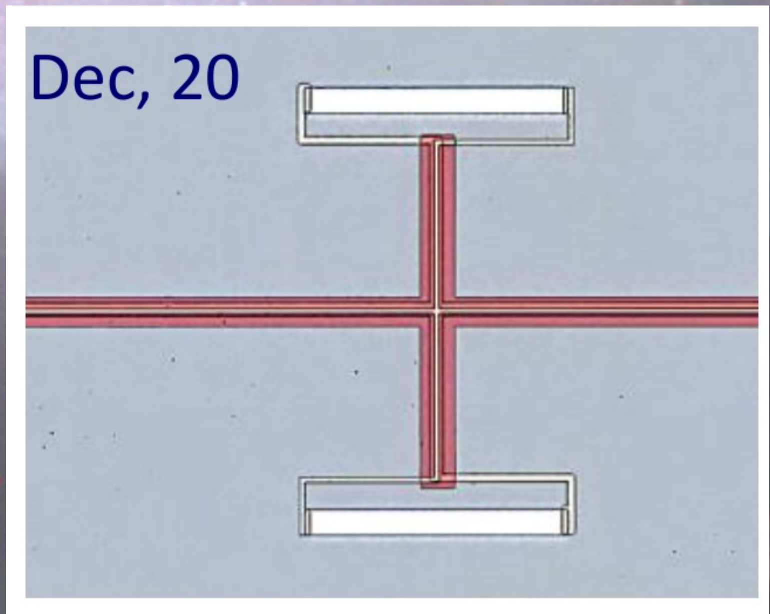


The results are good, the parasitic resistance disappear
but all the processes cascade needs to be retuned.

DM cleaning

Big improvement in pre and post processes cleaning routines.
Studies on density of contaminations to fix a requirements on chip cleaning





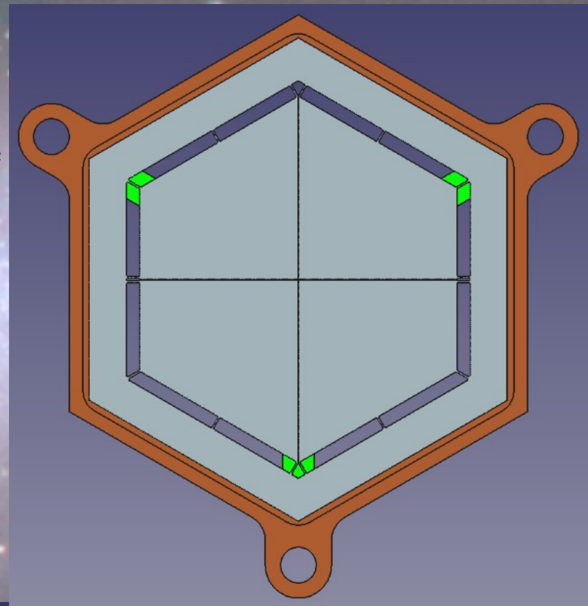
Structural model SM

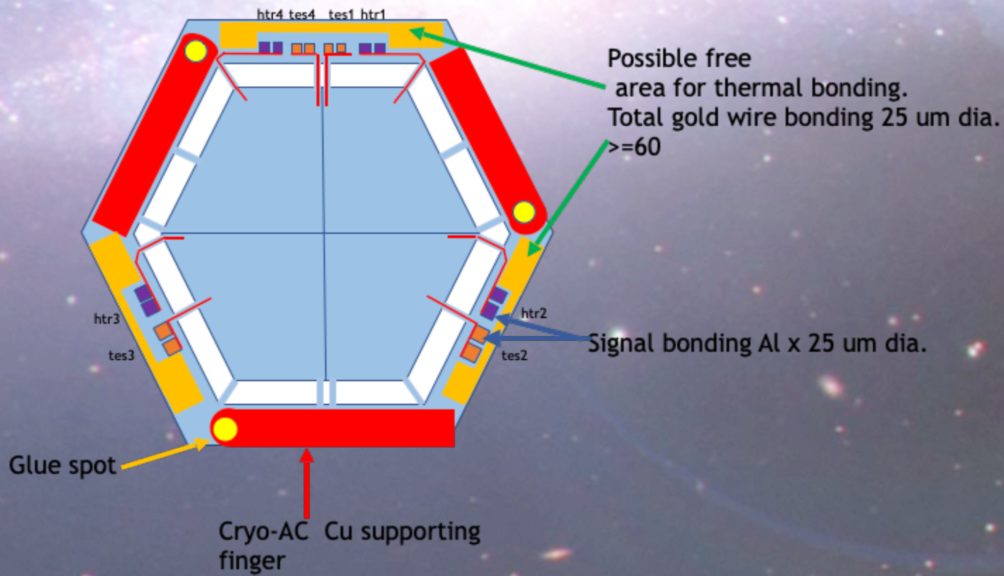
The final CryoAC structure will be hexagonal with a dimension about 4 times the DM.

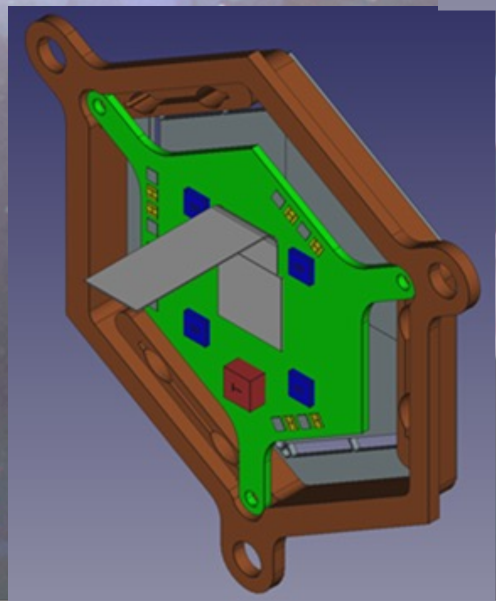
Two different configuration:

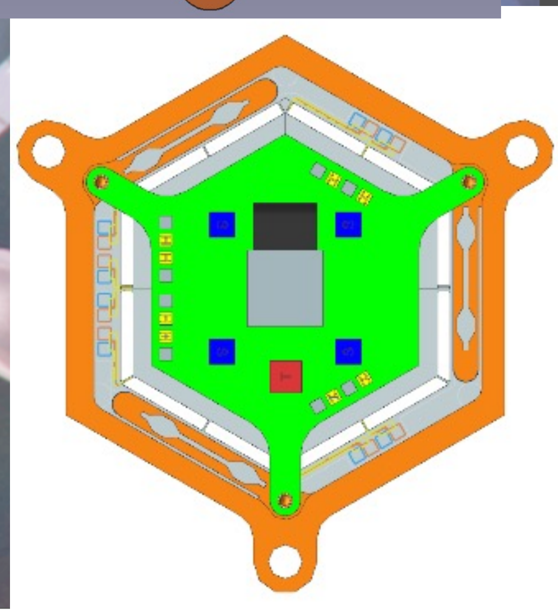
- Segmented. The hexagon is divided in four regions (**thermic capacity**, **mechanical properties**)
- Monolithic. Only one region (**thermic capacity**, **mechanical properties**)

All the production processes need to be adjusted for large structure.







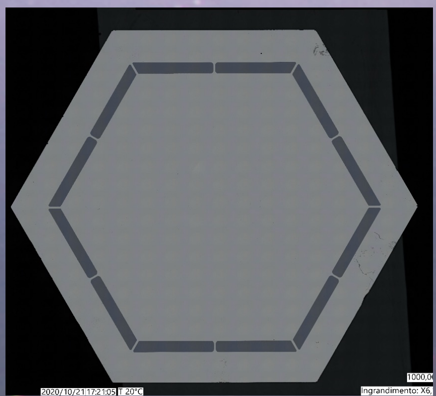


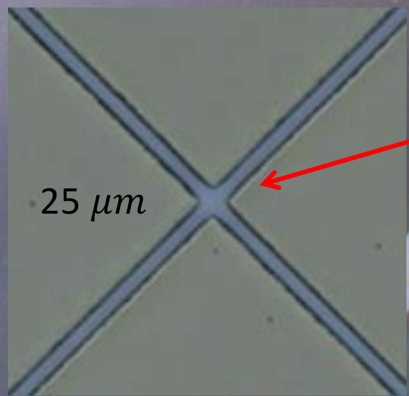
SM0 production and tests

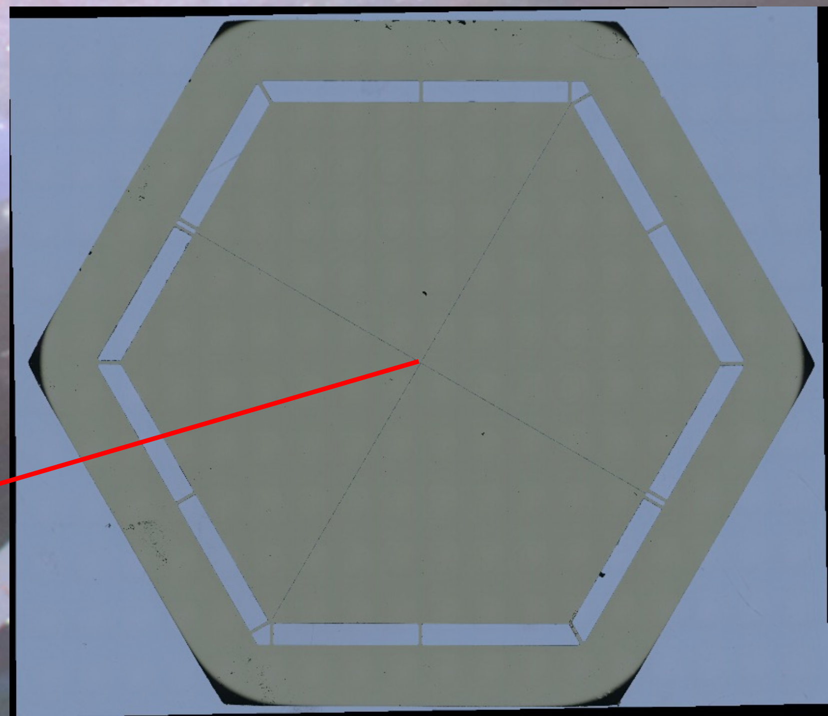
Structure model tests contemplated different phases:
Phase 0 – only mechanical structure with conductance bridges but without any detector structure
Phase 1 – dummy detector structure on a representative support structure
Phases 2 and 3, under discussion

Structural models will be tested for mechanical properties, vibrations, environment characteristic (humidity, temperature), thermic cycles.

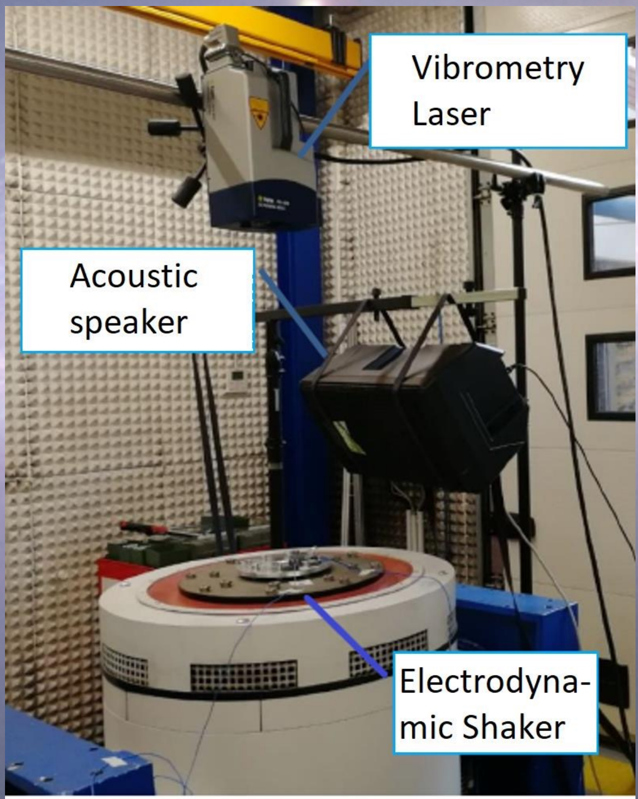
Different sample has been produced in Genova. Three, for each configuration, has been tested for mechanical vibrations at BPS facility in Milano



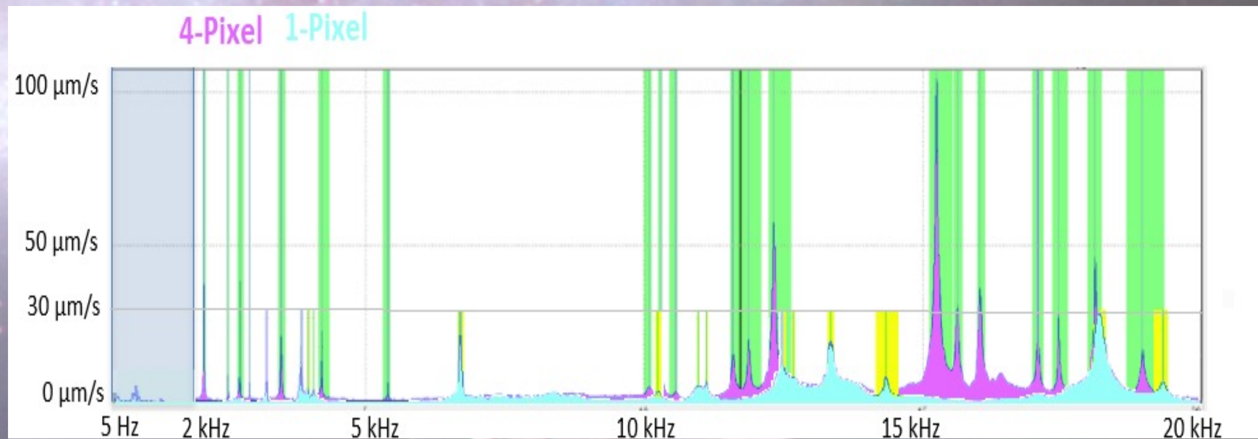




SM0 production and tests (2)



- BPS facility. Vibrating the samples with an Electrodynamic Shaker and reading vibrations with with a control sensor on the flank and with a laser on the chip



Both configurations show resonance out of critical region but monolithic far than segmented as expected. Test with representative support will be essential to final configuration selection.

Conclusions

- Dummy structure for athermal tests are on going.

- DM
  - Test at SRON demonstrated DM is compliant with the requirements of Athena.
  - The emerged problems have been fixed.
  - The tuning of production processes is on going to reach a better production yield and to move to large structure.

- SM
  - Both the geometries have passed the qualifying tests but the criticity on the 4-pixel one need further investigations
  - Replication of the structural test with a more representative setup (SM1, and others)